Litter Decomposition, Biomass, and Nutrient Concentration In Western Newfoundland Balsam Fir Forests

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by

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Summary

Balsam fir biomass was estimated in a chronosequence, aged 0–≥90 years, each within sites of good, medium, and poor quality, based on the Damman forest type classification system. Good and medium sites generally produced greater biomass than poor sites. Within good and poor quality sites aged 0–5 (clearcut) and 30–40 years, litter decomposition of balsam fir foliage, fine roots, herb shoots, shrub foliage, moss, and organic layer was measured after 1 and 2 years. Differences in decomposition between the good and poor sites, and between the clearcuts and the 30- to 40-year-old sites, varied with tissue type; there was no consistent trend in increased or decreased rates of decomposition with site quality or forest age. Litter decomposition was significantly higher in the first year; herb shoots and shrub foliage decomposed fastest, shrub twigs slowest. Balsam fir wood, branch, and coarse root decomposition was measured after 3 years only. Branch material decomposed significantly faster than wood or coarse root material, and rates of decomposition between sites for these tissues ranked: poor clearcut > good clearcut > good 30- to 40-year-old site > poor 30- to 40-year-old site. Overstorey and understorey tissue N and P concentrations were examined within a good and a poor 30- to 40-year-old site. Concentrations of N in overstorey, understorey, and forest floor tissue within the poor site were consistently lower than concentrations within the good site, indicating that the poor site was N deficient. There was no consistent trend with site quality for tissue P contents.

Keywords: *biomass, branch, Damman, foliage, moss, nitrogen, phosphorous, root, shrub, site quality, wood*

Résumé

Nous avons estimé la biomasse du sapin baumier dans des stations de qualité bonne, moyenne et médiocre, selon la classification des types forestiers de Damman, qui représentaient une chronoséquence de 0 à plus de 90 ans. En général, les stations bonnes et moyennes en produisaient davantage que les stations médiocres. Nous avons mesuré après 1 et 2 ans, dans des stations bonnes et médiocres de 0 à 5 ans (parterres de coupe à blanc) et de 30 à 40 ans, la décomposition de différents types de litière, entre autres : aiguilles de sapin baumier, racines fines, tiges d'herbacées, feuilles de plantes arbustives, mousses et couche organique. Les différences entre les stations pour la vitesse de décomposition varient selon le type de tissu sans qu'aucune tendance générale ne se dégage quant à un effet positif ou négatif de l'âge ou de la qualité des stations. Néanmoins, la décomposition de la litière a été significativement plus intense au cours de la première année. Les tiges des herbacées et les feuilles des plantes arbustives se sont décomposées le plus rapidement; les ramilles des plantes arbustives, le plus lentement. La décomposition du bois, des branches et des grosses racines du sapin baumier n'a été mesurée qu'après trois ans au sol. Les branches se sont décomposées significativement plus rapidement que le bois et les grosses racines, le classement des stations pour la vitesse de décomposition de ces tissus étant comme suit : station médiocre récemment déboisée > station bonne récemment déboisée > station bonne de 30-40 ans > station médiocre de 30-40 ans. Nous avons mesuré les teneurs en azote et en phosphore des tissus de l'étage supérieur et du sous-étage dans une station bonne et une station médiocre de 30 à 40 ans. Dans le cas de l'azote, les tissus de l'étage supérieur, du sous-étage et de la couverture morte de la station médiocre en contenaient toujours moins que ceux de la bonne station, ce qui indiquerait que la première était carencée en azote. Pour l'azote, aucune tendance générale en fonction de la qualité des stations n'a été mise en évidence.

Mots clés : *Azote, phosphore, biomasse, feuilles, végétation arbustive, racines, mousses, bois, branches, qualité de station, Damman.*

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Introduction

During the 1970s and 1980s, data on overstorey biomass, overstorey and understory tissue N and P contents, and decomposition of overstorey and understorey tissue were collected from across Canada to develop a computer simulation model, FORCYTE (Forest Cycling Trend Evaluator) to examine the long-term consequences of site nutrient capital and productivity of intense forest harvesting (Kimmins and Scoullar 1979). In Newfoundland, these data were collected from chronosequences of balsam fir on sites of good, medium, and poor quality, based on the Damman forest site classification system (Damman 1967). The system is an ecological classification system based on understorey characteristics and soil type, which are indicators of site fertility and potential tree growth (Damman 1967, Meades and Moores 1984). The Newfoundland and Labrador (NL) Forest Service is interested in managing NL forests on an ecological basis, using the Damman forest site classification system to identify and delineate forest ecological types (Moores *et al.* 1996). All earlier published studies examining the Damman forest types have focused on mature forests, and no previous publication has examined litter decomposition between sites based on Damman forest type. Within balsam fir forests, few published data sets are available that examine rates of tissue decomposition, especially within recently cleared balsam fir, and few studies have examined understorey or moss decomposition in boreal forests. Thus, these data will improve our understanding of forest growth and decomposition, and the effect of Damman forest type on these processes; they will aid in the management of balsam fir forests on an ecological basis.

In most boreal forests, balsam fir is a late-successional species (Thompson *et al.* 2003); it is the dominant forest type of Newfoundland's west coast. The annual allowable balsam fir cut for insular Newfoundland is approximately 1 million m^3, equivalent to half the annual allowable cut for the island. Black spruce largely fills the remainder (NL Department of Forest Resources & Agrifoods 1996). Boreal forests contain large stores of organic carbon (C) in living and dead tissue (Kurz and Apps 1999) that exchange significant amounts of C, largely in the form of CO_2, with the atmosphere through processes that are affected by forest management (Schimel 1995, Trofymow *et al.* 2002). Consequently, there is increasing pressure to manage forests to maximize fiber production while limiting the emission of C from forests to the atmosphere.

Litter decomposition is a critical ecosystem process that releases CO_2 to the atmosphere and regulates the transfer of C and nutrients to the soil, affecting nutrient availability. Decomposition also regulates the accumulation of fallen plant components that form habitat and fuel for fires. Decomposition is largely governed by climate and litter quality (Aber *et al.* 1990, Almendros *et al.* 2000, Sanger *et al.* 1998, Moore *et al.* 1999). The effect of litter quality, which is strongly influenced by tissue type, on decomposition is most pronounced during the first years of decomposition (Trofymow *et al.* 2002). Most studies on decomposition in forests have focused on aboveground tree components, such as foliage, bark, branches, and wood. Far fewer studies have examined the decomposition of roots, understorey herbs, shrubs, and moss, although these components may comprise a large proportion of the live biomass. For example, a large proportion of net primary productivity

is allocated to fine roots in boreal forests (Agren *et al.* 1980, Grier *et al.* 1981, Keyes and Grier 1981), where potentially more soil C comes from fine roots than aboveground biomass (Vogt *et al.* 1996). Also, thick layers of moss are common to the floor of the boreal forest. For example, live moss had a similar C content to the overstorey within mature black spruce stands of the northern BOREAS transect (Harden *et al.* 1997). Also, within unthinned black spruce stands in Quebec, the mass of the green moss layer was 1280–1310 kg/ha, producing biomass at rates equivalent to 33–50% of overstorey foliage and bole production, with an annual nutrient uptake of 23–53% that of the overstorey (Weetman and Timmer 1967). Although there are many studies of moss decomposition in peatlands and bogs (e.g., Hobbie 1996, Szumigalski and Bayley 1996), few studies have examined moss decomposition in forests. Decomposition dynamics of understorey and forest floor components, as well as overstorey components, are required to fully account for decomposition in forests.

Nutrient availability is an important driver of forest growth and the development of the Damman forest types (Damman 1967). Forest growth is commonly limited by low nutrient, and in particular N, availability, for example, in New Brunswick (Krause 1981) and Newfoundland (van Nostrand 1979). Tissue N and P content is also an indicator of tissue quality for decomposition (Berg 1984): initial decomposition rates are greatest with tissues of higher nutrient content. Therefore, we expect poorer quality sites to have lower overstorey and understorey tissue N and P contents, and lower rates of litter decomposition.

The aims of this study are:

1) To examine decomposition of tree foliage, shrub foliage, shrub twigs, herb shoots, moss shoots, organic layer, fine roots, coarse roots, wood, and branch material in good and poor forests, recently clearcut and aged 30–40 years.
2) To examine forest biomass in good, medium, and poor forests in a chronosequence of sites of ages 0–≥90 years.
3) To examine overstorey, understorey, and forest floor tissue N and P contents within good and poor 30- to 40-year-old sites.

Materials and Methods

Study Sites

Eighteen balsam fir forest sites were selected for study within the Western Newfoundland Ecoregion (Damman 1983), within the coordinates 58º 25' N 48º 75' W, 58º 20' N 48º 50' W, 57º 20' N 49º 22' W, and 57º 50' N 49º 15' W. The sites had a mean annual temperature of 3.0–5.1º C and received 987–1352 mm annual precipitation. Within each of six age classes (0–5 (clearcut), 8–12, 18–25, 30–40, 40–50, and ≥90 years), good, medium, and poor sites regrown following harvesting were selected for study. Damman site quality is primarily based on understorey vegetation and soil type, not forest growth, although it provides an indication of potential forest growth (Damman 1967, Meades and Moores 1984). Good sites are characterized by a dominant, herb-rich, shrub layer. The shrub layer was dominated by *Acer spicatum* and the herb layer was composed of *Rubus pubescens, Gallium trifiorum, Cinna latifolia, Cornus stolonifera*, and *Viola incognita*. Medium sites generally have ferns, dominated by *Dryopteris spinulosa* var. *americana*, and a well-developed feather moss (dominated by *Pleurozium schreberi*) layer with few *Acer spicatum* and *Betula lutea* shrubs. Poor sites have a moss-dominated understorey that consists primarily of *Pleurozium schreberi* with some *Hylocomium splendens* (Damman 1967, Meades and Moores 1984). The organic layer within the study sites was generally 10–15 cm deep. Balsam fir biomass was determined within good, medium, and poor sites from each age class. Rates of litter decomposition were measured within each of a good and a poor clearcut and 30- to 40-year-old site. Concentrations of overstorey and understorey nutrients were determined within a 30- to 40-year-old good and poor site.

Aboveground Biomass

Aboveground biomass was estimated within a site from each site quality and age combination using the Point Centered Quarter Method (Cottam and Curtis 1956). Distances to dominant and nearest tree from random points and tree heights and diameters at breast height (1.3 m), in combination with biomass regression equations (Lavigne 1982), were used to estimate aboveground biomass and stand density. For quadrants without trees, a correction factor described in Warde and Petranke (1981) was applied.

Tissue Sampling

Aboveground forest and understorey tissues were sampled for nutrient content and the decomposition study using the Point Centered Quarter Method (Cottam and Curtis 1956) during June 1985. A 100-m transect of random bearing and origin within each site was established where ten sample plots with a 0.56-m radius were established at 10-m intervals along the transect. Within sample plots, aboveground portions of shrubs, herbs, seedlings, and litter were collected, dried, and weighed. Moss and organic layer material was sampled within a 25 X 25 cm subplot within the 0.56-m radius sample plot. Small roots (diameter #2.0 mm) were separated from the organic material, which was sampled to the top of the mineral soil. Balsam fir foliage was sampled from litter traps installed in mature stands

during the summer of 1984 to be used in the decomposition study. Fifteen trees within each of a 30- to 40-year-old good and poor site were felled and sampled for current and 7-year-old (oldest living) foliage N and P contents. Current foliage was taken from the upper, middle, and lower crown, including terminal and lateral branch leaders. Seven-year-old foliage was taken from throughout the crown. Five of the original 15 trees were sampled for current, oldest, and dead branches, sapwood, heartwood, and bark. Subsamples of tissue were dried at 70º C to constant weight, weighed, ground, and analyzed for N and P using automated colorimetric procedures.

Tissue Decomposition

Within-site decomposition was based on tissues collected within each site only. Fiberglass (2 mm) mesh was used to construct 156.0 cm^2 litterbags that were filled with 2 g of balsam fir foliage collected from litter traps, herb shoots, or moss shoots or 4 g of shrub foliage, shrub twigs, or fine roots. Fine, 25-cm^2 nylon mesh litterbags were filled with 7 g of organic layer material. Each litter type above was individually placed within ten litterbags placed within each of the good clearcut, poor clearcut, good 30- to 40-year-old, and poor 30- to 40-year-old sites in June 1985. Half the litterbags were retrieved after 1 year and half after 2 years following placement. At the same time, ten pieces of balsam fir stemwood (0.5–8 kg), branch (less foliage; 20–70 g), and coarse (>10 cm) root (9–47 g) material were placed within each of the four sites above and retrieved after 3 years. Retrieved litter was dried to constant mass and weighed. Litter decomposition was the loss of litter mass over time.

Statistical Analysis

Means of decomposing tissue masses, within tissues between sites or years and within sites between tissues, were compared using least significant difference where a one-way analysis of variance showed a significant difference between means ($p \leq 0.05$). All other means were compared by simple ranking.

Results

Decomposition

After 2 years, within bagged litter, shrub twigs and moss had decomposed significantly less than other tissues, with few exceptions. However, an unexplained increase in moss litter occurred between years 1 and 2. In year 1, moss decomposition was comparable to that of fine root and herb shoot, and significantly slower than shrub twig decomposition. Herb shoots and shrub foliage decomposed significantly faster than other tissues in all site and age combinations, except for organic material at the poor 30- to 40-year-old site in year 1. Tree foliage, organic layer, and fine roots decomposed at similar rates, intermediate to other tissues. All tissues decomposed faster in the first than in the second year of decomposition (Table 1).

Table 1. Proportion of initial tissue weight remaining after 1 and 2 years of decomposition in four balsam fir forests

	Good Sites		Poor Sites	
Tissue	**Clearcut**	**30- to 40 year-old**	**Clearcut**	**30- to 40 year-old**
After 1 year				
Fir foliage	0.73 d	0.73 e	0.73 cd	0.70 d
Shrub foliage	0.51 b B	0.50 b B	0.43 a A	0.60 b C
Shrub twigs	0.81 e B	0.75 e A	0.86 f C	0.82 e B
Herb shoots	0.33 a B	0.20 a A	0.77 e C	0.25 a A
Moss shoots	0.66 c BC	0.63 cd A	0.74 d C	0.69 cd B
Organic layer	0.65 c B	0.67 d C	0.65 b AB	0.64 bc A
Roots	0.67 c AB	0.61 c A	0.73 c BC	0.77 e C
After 2 years				
Moss shoots	0.67 d A	0.74 de B *	0.65 c A	0.68 c A *
Shrub twigs	0.41 b B	0.45 b B	0.20 a A	0.41 b B
Fir foliage	0.76 e B	0.60 c A	0.81 d C	0.77 d BC
Organic layer	0.19 a	0.24 a *	0.34 b	0.21 a *
Roots	0.74 e B	0.77 e B	0.67 c A	0.81 d C
Shrub foliage	0.66 d B	0.67 cd B *	0.64 c * A	0.67 c B
Herb shoots	0.55 c	0.62 c *	0.66 c *	0.63 c
After 3 years				
Wood	0.85 b A	0.88 ab A	0.81 c A	0.90 a A
Branch	0.64 a B	0.66 a B	0.60 b B	0.66 a B
Coarse root	0.84 a A	0.92 a C	0.65 c C	0.93 a C

Lowercase letters denote significant differences within columns and years.
Uppercase letters denote significant differences within rows.
Denotes differences in mass loss between year 1 and 2 for tissues indicated were not significant ($p < 0.05$), all other differences, including comparisons to initial masses, were significant at the $p < 0.05$

Table 2. Proportion of wood, branch, and coarse root (>10 mm diameter) initial weight remaining after 3 years decomposition in four balsam fir forests

	Site Quality and Age			
Tissue	**Poor clearcut**	**Good clearcut**	**Good 30- to 40-year-old**	**Poor 30- to 40-year-old**
Wood	0.81 c	0.85 b	0.88 ab	0.90 a
Branch	0.60 b	0.64 a	0.66 a	0.66 a
Coarse root	0.65 c	0.84 a	0.92 a	0.93 a

Letters denote significant differences within a row.

Table 3. Biomass (mg/ha) and stem density of balsam fir tissue within good, medium, and poor quality sites

		Biomass (mg / ha) According to Stand Age (Years)					
Site type	**Tissue**	**0–5**	**8–12**	**18–25**	**30–40**	**40–50**	**>90**
Good	Foliage	0.04	10.2	15.8	39.1	12.8	13.0
	Stemwood	0.03	11.3	54.1	105.5	68.5	78.5
	Stembark	0.01	2.9	10.3	20.7	12.4	14.2
	Branches	0.03	5.7	16.8	33.9	20.1	22.9
	Total	0.10	30.1	96.9	199.1	113.9	128.6
Medium	Foliage	0.18	10.6	21.8	21.4	12.0	22.2
	Stemwood	0.10	10.0	57.2	60.6	46.2	128.1
	Stembark	0.05	3.2	11.3	12.0	8.6	23.2
	Branches	0.10	6.1	18.7	19.9	14.0	37.7
	Total	0.43	29.8	108.9	113.9	80.8	211.2
Poor	Foliage	0.07	6.4	20.0	18.3	15.4	15.7
	Stemwood	0.04	6.7	63.5	43.7	50.8	84.8
	Stembark	0.02	1.9	12.5	8.9	9.7	15.4
	Branches	0.05	3.7	20.9	15.1	16.2	25.3
	Total	0.18	18.7	117.0	86.0	92.1	141.3
				Stems / ha			
Good		1462	35 600	10 279	29 412	1997	757
Medium		9545	147 929	15 242	19 290	3835	2014
Poor		14 323	38 462	20 362	18 182	8737	2301

There was no clear trend in rates of decomposition between sites for bagged litter, however, decomposition of unbagged wood, branch, and coarse root material ranked higher in the younger sites than in the older sites, where differences were significant within the poor sites (Table 2). The varying initial weight of unbagged litter creates large differences in decomposable surface area:volume ratios, potentially affecting results. This is likely to have contributed to the slow decomposition of stemwood compared with branch and coarse root material. Therefore, these findings need to be confirmed with standardized tissue masses.

Balsam Fir Biomass and Tissue Concentration

The poor site ranked highest for biomass only in the 18- to 25-year age class. Variability in tree biomass between age classes, both within and between site qualities, was large. This variability, at least in part, resulted from a variation in magnitude of two orders in stem density, where the medium 8- to 12-year-old site had a very high stem density of 148 000 stems/ha (Table 3). For all tissues examined within the 30- to 40-year-old forests, the good site ranked above the poor site for N content, but neither site had consistently greater P contents within examined tissues (Table 4). The N and P contents of balsam fir within the good and poor 30- to 40-year-old sites can be estimated by assuming the biomass from Table 3 has N and P contents equivalent to the live components of Table 4, or the average of young and old tissues where both are provided. Using this method, the balsam fir N content within the good and poor sites was 610 and 348 kg N ha^{-1}, respectively, where foliage, stemwood, stembark, and branches contained 78, 17, 1, and 4% aboveground N in the good site, and 57, 8, 8, and 27% aboveground N in the poor site, respectively. Similarly, the balsam fir P content within the good and poor sites was 11.3 and 6.4 kg P ha^{-1}, respectively, where foliage, stemwood, stembark, and branches contained 42, 23, 4, and 32% aboveground P at the good site, and 38, 17, 9, and 36% aboveground P at the poor site, respectively.

Table 4. Nutrient concentrations of 30- to 40-year-old balsam fir overstorey, understorey, and forest floor tissues

Tissue		Good Site		Poor Site	
		N (g kg^{-1})	P (µg g^{-1})	N (g kg^{-1})	P (µg g^{-1})
Balsam fir					
Foliage	New:				
	Upper Crown	13.7	157	13.4	166
	Middle Crown	13.7	150	12.1	165
	Lower Crown	13.5	148	11.5	163
	Old	10.5	91	9.4	100
	Dead	13.1	94	10.3	85
Wood	Living	9.7	25	<0.6	< 25
	Dead	0.6	25	<0.5	< 25
Bark		3.9	53	3.2	62
Branches	New	11.3	192	8.0	212
	Old	4.7	72	4.3	90
	Dead	1.9	25	1.5	< 25
Shrub					
Foliage	Living	29.4	198	22.4	250
	Dead	10.8	92	7.8	48
Twigs	Living	6.8	66	3.7	36
	Dead	9.9	150	Na	
Herb					
Shoots	Living	19.0	156	Na	
	Dead	12.1	88	8.5	132
Moss					
Shoots	Living	12.7	214	8.7	185
	Dead	13.0	146	8.4	120
Organic Layer		16.7	86	9.6	79

Discussion

As expected, litter mass losses were greatest in the first year of decomposition, except for herb shoots in the poor clearcut, which lost roughly 0.3 original mass in both years of decomposition (decomposition in the first year may have been reduced because of surface drying with increased surface incident solar radiation following the removal of the canopy). During early decomposition, good quality litter is decomposed rapidly (Preston *et al.* 2000). Also, significant litter mass is lost through leaching of soluble compounds, which include some decomposition-retarding chemicals such as tannins, further enhancing decomposition (Trofymow *et al.* 2002). Litter chemistry is a good predictor of tissue mass loss during initial decomposition, which follows an exponential decay (Aber *et al.* 1990). In later years, mass loss converges for litter of various initial qualities, where decay rates may be determined by recalcitrant cell-wall components and lignin (Melillo *et al.* 1982), common to the slow-decaying woody litters of this study.

The 30- to 40-year-old good site had overstorey and understorey tissues with higher N concentrations than the poor 30- to 40-year-old site. Good quality sites potentially produce litter of higher quality that decomposes faster than litter from poorer sites. However, rates of decomposition of overstorey and understorey tissue from good and poor sites were similar, except within the clearcut (Tables 1 and 2), indicating that litter qualities were also similar. Although rates of decomposition between the good and poor sites were similar, litter from the good site had higher N contents (Table 4), and thus, larger amounts of N are cycled through litter and made available for plant growth. In addition, litterfall and leaf litterfall are generally positively correlated with forest productivity (Thomas 1992), further increasing the amount of nutrients cycled within good sites. Differences in decomposition within the clearcuts are likely to be affected by site-specific changes in temperature and moisture regimes following forest clearing (Binkley 1984). Comparisons of decomposition of individual tissue types between sites are confounded by the lack of a standardized litter source, which potentially explains some of the variations, or lack of variations, observed between sites within litter types.

Herb shoots and shrub foliage were of highest quality across all sites, losing up to 0.8 original mass over 2 years, with relatively large proportions of mass loss occurring in both years. Moss exhibited one of the slowest rates of bagged litter decomposition after 2 years; however, after 1 year, moss decomposed at intermediate rates for bagged tissues, decomposing faster than balsam fir foliage, which is contrary to Szumigalski and Bayley (1996), who found moss to be more resistant to decomposition than vascular plants. There was an unexplained increase in moss mass from year 1 to year 2, which probably resulted from loss of moss tissue through the 2-mm litterbag mesh during litterbag collection after the first year of decomposition. Thus, moss tissue may have also been lost in year 2, resulting in an overestimation of moss decomposition in both years; litterbags of a mesh finer than 2 mm are required when examining moss decomposition. In agreement with Berg (1984), fine roots decomposed at similar rates to overstorey foliage. Root decomposition, which is primarily driven by root chemistry rather than climate (Silver and Miya 2001), may account for as much as one half of the annual carbon addition to forest

soils (Coleman and Crossley 1995). It is common to bury roots during decomposition studies, rather than leaving them on the surface as in this study, which exposes the decomposing roots to conditions different from those on the surface, potentially altering rates of decomposition. Rates of organic layer material decomposition were comparable to those of roots and moss shoots, and only slightly less than those of fir foliage, indicating that the forest floor comprises relatively young decomposable material.

Forest clearing increases soil solar incident radiation, increasing soil temperatures, which potentially improves soil moisture conditions and rates of decomposition (Pritchett 1979, Spurr and Barnes 1980). Forest carbon budget models often assume forest clearing increases rates of decomposition (*e.g.*, Harmon *et al.* 1990, Kimmins *et al.* 1982, Kurz and Apps 1999). Within the study sites, depending on the tissue, decomposition was increased, decreased, or unaffected by forest clearing. Others have found no change (Binkley 1984, Prescott *et al.* 2000), slowed (Blair and Crossley 1988, Yin and Perry 1989), and increased (Prescott *et al.* 1993, Taylor *et al.* 1991) decomposition following forest clearing, indicating the need for further research into the dynamics of decomposition following harvesting.

Stem biomass was within the range derived from the NL Forest Service growth and yield tables (unpublished); branch and foliage biomasses in the good quality, 30- to 40-year-old site were in the upper range for balsam fir reported by Lavigne *et al.* (1996). There was no increase in forest biomass or stocking with site quality within the study sites. Others have attempted to use the Damman forest types as predictors of growth. For example, Page (1976) found soil moisture regime (as indicated by soil and forest floor parameters) was the major predictor of growth, however eight site-variable equations were necessary to achieve satisfactory levels of prediction, where many variables required complex laboratory analysis, negating the use of these equations as an operational tool in practical forest management. Page (1976) notes the Damman forest types, although meaningful in ecological terms, do not provide a precise delineation of forest productivity classes and cannot easily be assigned to disturbed sites. More recently, studies were initiated that examined a range of forest attributes within Damman forest site types as indicators of forest growth and management (Roberts *et al.* 1996), however this work has stalled and is still incomplete. As site quality improves, a more vigorous understorey vegetation develops (Damman 1967) that will be associated with increased competition between the understorey and overstorey, potentially reducing forest growth and stocking at some sites.

Young, unthinned, balsam fir stands commonly have tens of thousands of stems per hectare (for example, 62 000 (Karsh *et al.* 1994)); however, a stocking of 148 000 stems/ha at the medium, 8- to 12-year-old site is very high, beyond any previously published balsam fir stocking. There was no trend with increasing stem densities with site quality. Stem densities within all site qualities within the study sites remained high until the stands were 40–50 years of age, when self-thinning reduced stem densities below 9 000 stems/ha. The increase in site quality, although not reflected in overstorey density or growth rates, was reflected in increases in overstorey and understorey tissue N concentrations and contents;

however, there was no trend with tissue P concentrations, indicating the poor site was P sufficient, but N limited.

Because these data were collected to support the development of a national forest simulation model, they differ in their collection methods from studies designed to examine differences in forest attributes between forests grown on different quality sites located in western Newfoundland. This study lacks replication within site quality and age combinations, and does not limit variation of overstorey stem densities, at least within each site quality class, as is commonly done in investigations of site quality on forest attributes. It is also common to use a standardized litter source across all sites during decomposition studies, rather than litter collected within each site.

In summary, there was no consistent increase or decrease in decomposition between clearcut and 30- to 40-year-old sites or between good and poor sites. Good and medium sites generally had greater overstorey biomass than poor sites. Stand density did not significantly decrease until 40–50 years of age and within a medium, 8- to 12-year-old site, a very high density of 148 000 stems/ha was found. A good site consistently ranked higher than a poor site for tissue N concentrations, indicating that the poor site was N deficient. However, the data were collected to develop a national forest growth model, and results require substantiation with results from additional sites using more standard procedures.

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